Modeling Antennas on Automobiles in the VHF and UHF Frequency Bands, Comparisons of Predictions and Measurements

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Abstract: This paper describes comparisons of analysis and measurements of antenna patterns on automobiles in the VHF and UHF frequency bands. The actual measurements and analysis were performed at six different frequencies ranging from 41 MHz to 918 MHz. An antenna on a vehicle in a roadway environment in the presence of Earth does not have antenna patterns or input impedances as if it were located in free space or over a perfectly conducting ground plane. Antenna patterns of a whip antenna on a vehicle were measured on an outdoor antenna range with the vehicle on a 10 meter diameter turntable. Patterns were also measured with the vehicle over real ground away from the turntable to determine the effects of the steel turntable on antenna patterns. The three-antenna gain measurement technique was used to measure antenna gain. The measured patterns and gains were compared to predictions using the Numerical Electromagnetics Code (NEC-4) [1].

1. Introduction

This paper discusses the modeling of antennas on automotive vehicles at VHF and lower frequencies. Comparisons of predictions to measurements were also made to verify results. There is considerable interest in the performance of antennas on automotive vehicles for both public safety and military communications, since it has a significant effect on communication performance. Public safety mobile communication systems use some VHF frequencies (30 to 50 MHz, 132 to 178 MHz, 406 to 420 MHz, 806 to 824 MHz and 851 to 869 MHz). The military uses mobile communication systems in the 30 to 88 MHz frequency band and other VHF and UHF frequency bands. An antenna on a vehicle in a roadway environment does not behave as if it were in free space or over a perfectly conducting ground plane. The antenna pattern tends to angle upward away from the ground resulting in a significant reduction in antenna gain at low elevation angles, and hence reduced performance. Accurate antenna modeling is necessary to determine the elevation and azimuth gain variability for prediction of the actual gain to be used in launching the electromagnetic wave at the appropriate elevation angles. The gain of the antenna is a function of the antenna geometry, materials used, antenna height above ground, ground conductivity, ground dielectric constant, frequency, elevation angle, and azimuth angle. The performance of an antenna near or on the surface of the Earth is very dependent on the interaction with the lossy Earth and the automotive vehicle. The Numerical Electromagnetics Code (NEC-4) was used to model these antennas with method-of-moments techniques [1]. Conventional methods involving the use of free-space antenna gain performance for the antennas could not be used here due to the close proximity of the antennas with respect to a lossy Earth and the metallic automotive vehicle. Investigation results show that depending on the relative geometry of the communication scenario, differences between free-space antenna gain and the actual gain can be on the order of 8 to

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30 dB for a typical antenna and vehicle over real Earth. These lower gains occur at the low elevation angles (less than 3 degrees) typical of a scenario involving a geometry for broadcasting to a vehicle, or for two-way communications between vehicles, or between vehicles and the roadside. By including the correct antenna gain in the propagation loss predictions, a good agreement with measurements was obtained for the long-range minivan measurements. The analysis results will be presented here with correlation to measurements. This original antenna analysis work was initially performed to supplement a measurement and prediction of coverage study that determined the service area of an FM Subcarrier Broadcast System [2]. The coverage study was performed in support of the Federal Highway Administration to independently evaluate the performance of an FM subcarrier-based traveler information broadcast system. This original antenna analysis work supplemented this coverage study by determining the antenna performance of antennas on automotive vehicles to aid in predictions and measurements of radio-wave propagation [2,3]. Recently, the antenna analysis was expanded to cover other frequencies in the VHF and UHF bands where antennas would be used on a sport utility vehicle (SUV) that would be of interest to the public safety community. The antenna pattern measurements were made with the vehicle both on and off of a ten meter diameter turntable. Additional measurements were performed to determine the effects of the turntable on measured antenna patterns and gain.

Computational electromagnetics using analytical mathematical expressions are difficult to apply to these types of practical problems, but the use of numerical techniques such as the method-of-moments makes the solution of the problem tractable.

2. Discussion

This paper presents the results of an investigation of antennas mounted on automotive vehicles where predictions were correlated to measurements. In the VHF band, the method-of-moments technique in NEC-4 can easily and accurately model antennas on automotive vehicles. Above the VHF band the method-of-moments technique requires a larger number of wire elements to accurately model the antennas and the vehicles. This requires an excessive amount of computation time. This study examined this problem of modeling antennas at the higher frequencies and determined what the limitations were when constrained to a practical limit on computation capability versus segment size. The method of moments analysis technique for modeling antennas and related structures requires that the antennas be modeled with wire segments and patches whose dimensions are on the order of a tenth of a wavelength in order to accurately represent the structures. In this study for frequencies above 411 MHz, the segment lengths were greater than a tenth of a wavelength. The effects of using the longer segment lengths at the higher frequencies were then determined by comparison to measured data.

The minivan that was used as a test vehicle as well as the SUV were modeled using wire segments, since there was more flexibility and freedom in using wire only segments, rather than a combination of patches and wire segments. The roof of the vehicle was modeled using a rectangular grid of wires to provide multiple locations to mount the antenna on the surface and also provide adherence to the $2\pi r$ foldout rule. This rectangular configuration was found superior to the radial wire technique of modeling vehicle surfaces. The antenna impedance is more stable and agrees better with measured data. Extensive modeling efforts also determined that the four sides of vehicles had to be modeled to accurately depict antenna behavior and the asymmetry of the van or SUV. The modeling of an antenna on the roof,

using just the roof structure without sides to represent the vehicle was not adequate. Modeling antennas using this computer model clearly demonstrates that the pattern of an antenna on a vehicle does not behave as if it were in free space or on perfectly conducting ground. There is a reduction in gain at and near the horizon, because the beam maximum does not occur near the horizon or at low elevation angles like it would for the conditions of perfectly conducting ground or free space. This is due to the nature of the test antenna and the effects of real ground. The turntable also has an effect on the antenna pattern, which was also investigated.

Previous FM subcarrier measurements verified both the antenna pattern gain and radio-wave propagation predictions for the minivan test vehicle [1]. The measured signal levels into the receiver on the test vehicle were compensated for using the calculated elevation gain response of the receiver antenna for the measurement and prediction comparisons [1]. The receiver antenna gains at low elevation angles that were determined by analysis were much lower than would normally be expected. The angle for the most common scenarios was approximately three degrees or less with respect to the horizon. This was true even for the case of an elevated FM radio station transmitting antennas on mountains such as that used for comparison of measurements and predictions. The FM station transmitter was at an altitude above mean sea level of 10597 feet (3231.79 meters) and the antenna was mounted on a tower 236 feet (71.95 meters) above that altitude. The average height of a receiver antenna for the test vehicle was at the average altitude of 5280 feet (1609.76 meters) plus the height of the antenna of 1.9 meters above this altitude. Using the heights of the receiver and transmitter antenna to determine the scenario geometry, the resulting elevation angles from the receiver to the transmitter for distances of 30 km, 97 km, and 145 km are approximately 3.0, 1.0, and 0.7 degrees, respectively.

Another significant effect on the pattern is that due to the multipath environment. Multipath effects are difficult to predict and are very dependent on the scenario geometry of the surrounding environment, so they were not included in this antenna study. However, multipath effects were actually measured in the coverage study using the van, but not the SUV.

When antenna patterns were measured on the turntable using the SUVat the antenna range, the metal turntable and Earth had a significant effect on the measurement. The effects of the Earth are included in the measurement, but unfortunately the undesirable effects of the metal turntable and the surface wave at short range are also included in the measurement. The effect of the surface wave, which is also part of the ground wave can be included in the modeling, and its quantitative effects can be determined for the purpose of factoring it out of the measurement. The surface wave is still significant even at higher frequencies at short distances and has a considerable effect on the measured antenna patterns. This effect must be factored out of the measured data, since it will give a false indication of true antenna performance at longer distances, because the surface wave attenuates rapidly with increasing distance. The surface wave will fill in the measured pattern at the lower elevation angles at short distances, resulting in a much larger antenna gain at low elevation angles. The antenna pattern of the antenna on the SUV was measured at short distances, so the surface wave was still present and significant in amplitude. The previous antenna measurement results with the minivan were at long distances, so the surface wave was attenuated to a negligible level. The effects of the turntable can also be predicted and factored out of the measured antenna data.

3. Conclusions

Modeling antennas using the NEC-4 computer model clearly demonstrates that the pattern of an antenna on a vehicle does not behave as if it were in free space or on perfectly conducting ground. There is a reduction in gain at and near the horizon, because the beam maximum does not occur near the horizon or at low elevation angles like it would for the conditions of perfectly conducting ground or free space. This is due to the nature of the test antenna and the effects of real ground. The results of the study using the SUV permitted the required antenna pattern correction to be made to the measured antenna pattern. These corrections factor out the effects of the surface wave and the metal turntable. The corrections can be used for short-range measured patterns of antennas on automotive vehicles over Earth, or the automotive vehicle on the turntable in the presence of Earth.

4. References

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